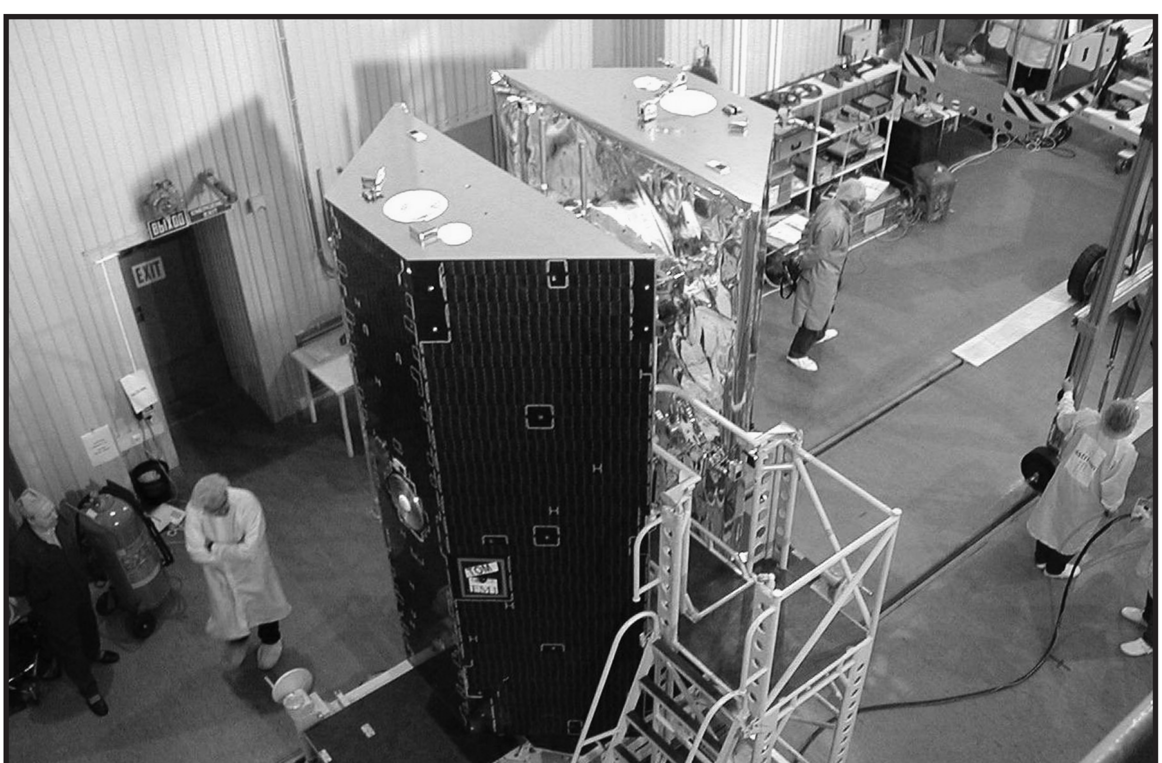
Gravity Recovery and Climate Experiment

The GRACE mission consists of two identical spacecrafts flying in the same orbit, about 220 kilometers apart at a height of approximately 500 km. The pair, unofficially nicknamed “Tom and Jerry”, orbit the Earth in about 95 minutes. The mission began on March 17, 2002 from the Plesetsk Cosmodrome in Russia. While the experiment was planned to last 5 years, it is still going strong after 7 years, providing valuable data for Earth sciences.

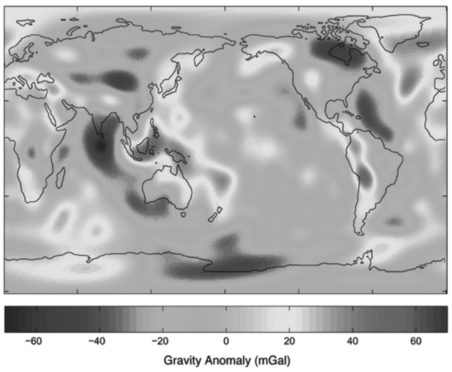
The concept that gravity is not constant, that it changes with location and in time as the mass distribution of the Earth changes, is well known to scientists, but was generally unfamiliar to students and the general public - until now. As GRACE has mapped the Earth’s gravity field and its variations from month to month, the results describing our dynamic Earth system are making headlines. The changes in the ice sheets in Antarctica, Greenland, Alaska and South America are among the most notable observations. Tiny changes in the Earth’s gravity – due mostly to the movement of water around the planet – are critical for making predictions about the Earth’s climate. These precise gravity field measurements, combined with other satellite and in situ (ground) measurements, underpin a large variety of climate-change-related studies in oceanography, hydrology, glaciology, and solid-Earth sciences.



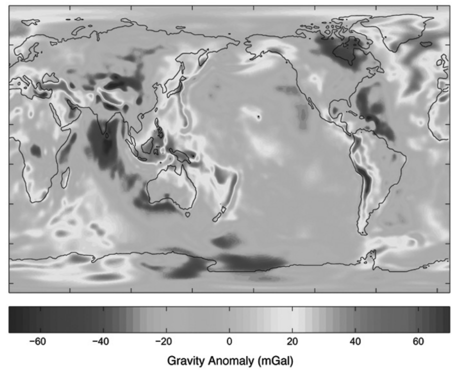
The GRACE spacecraft, unofficially nicknamed “Tom and Jerry”

GRACE - *Science in a Nutshell*

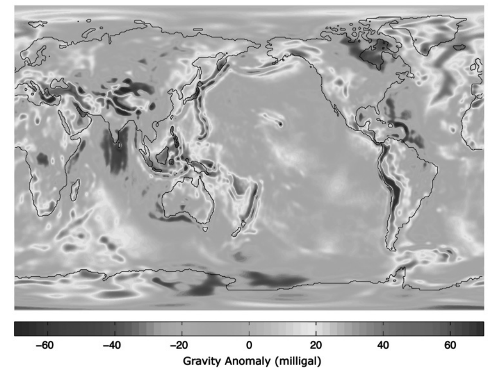
GRACE is measuring gravity at an UNPRECEDENTED level of precision, on the order of a few parts per billion of g, which is the nominal value of the gravitational acceleration on the Earth's surface (~9.8 m/s^2). The dramatically improved map of the mean Earth gravity field helps to refine our knowledge of the composition and structure of the Earth, and it provides the accurate reference surface relative to which deep ocean currents can be determined.



Best resolution gravity map available before GRACE



Gravity map with 111 days of GRACE data



Latest gravity map using 4 years worth of GRACE data

GRACE is UNIQUE, as it gives a global, consistent and uniform quality measurement of mass flux (movement of material around and within the Earth), observing geophysical processes within every one of the Earth's sub-systems (land, ocean, atmosphere, terrestrial water storage and ice sheets). *See Greenland and Sumatra-Andaman on front*

Of particular interest for understanding the Earth's climate system, **GRACE MONITORS** the movement of water over the Earth's surface with a level of detail never seen before. *See Amazon on front*

GRACE spans ALL of geosciences; the results address questions within the "Climate/Variability", "Water Cycle" and "Earth Surface & Interior" focus areas of NASA's Earth science priorities.

The measurements **GRACE** is providing from Earth orbit would be impossibly expensive if it were done on the ground - **THERE IS NO SUBSTITUTE** for observing the whole Earth from Space.

GRACE is a joint project of the American space agency NASA, the German Aerospace Center (DLR), the University of Texas Center for Space Research (CSR), GeoForschungsZentrum Potsdam (GFZ) and the Jet Propulsion Laboratory.

Aligning with Standards

NCES Standards	ACTIVITY & GRADE LEVEL		
	GRACE Model 4-8	Gravity 6-12	Greenland 7-12
Science as Inquiry - Abilities Necessary to Do Scientific Inquiry – Process of Scientific Inquiry		X	X
Physical Science - Properties and Changes in Matter – Motions and Forces – Transfer of Energy			X
Earth and Space Science - Structure of the Earth System – Earth's History – Solar System			X
Science and Technology - Technological Design – Science and Technology	X	X	
Science in Personal and Social Perspectives - Role of Science and Technology in Society		X	X
History and Nature of Science - Science is a Human Endeavor, History of Science, Nature of Science		X	X

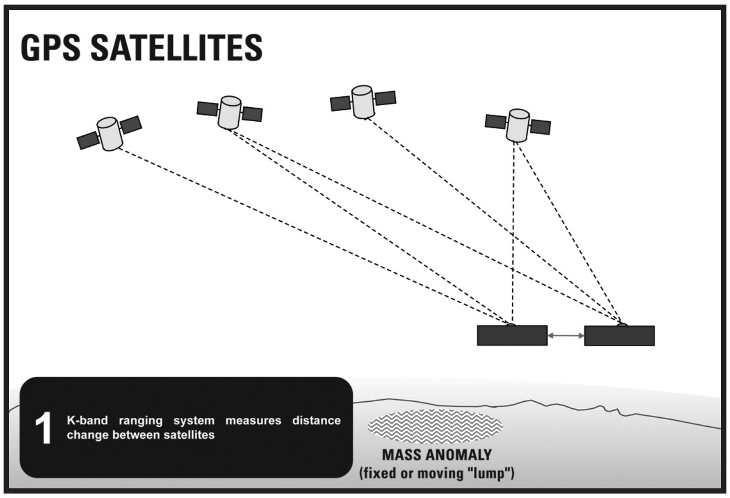
NCTM Standards	GRACE Model	Gravity	Greenland
Geometry			X
Measurement	X		X
Data Analysis and Probability			X

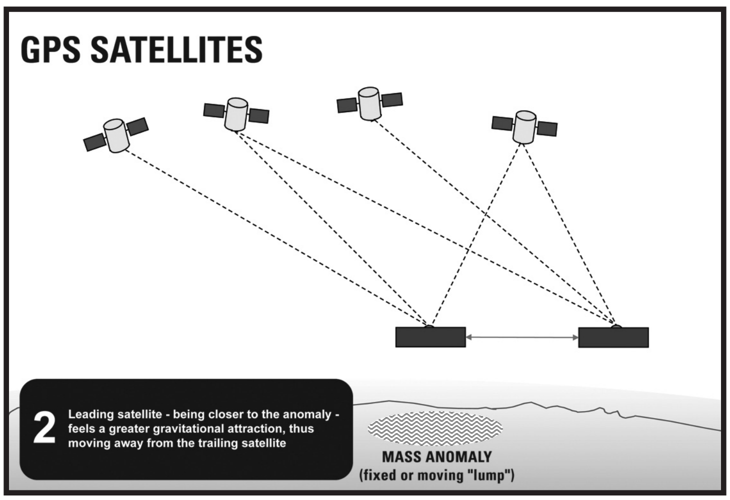
STL Standards	GRACE Model	Gravity	Greenland
Nature of Technology - Standards 1, 2, 3	X		
Design - Standards 8, 9 10		X	
Abilities for a Technological World - Standard 11	X	X	X

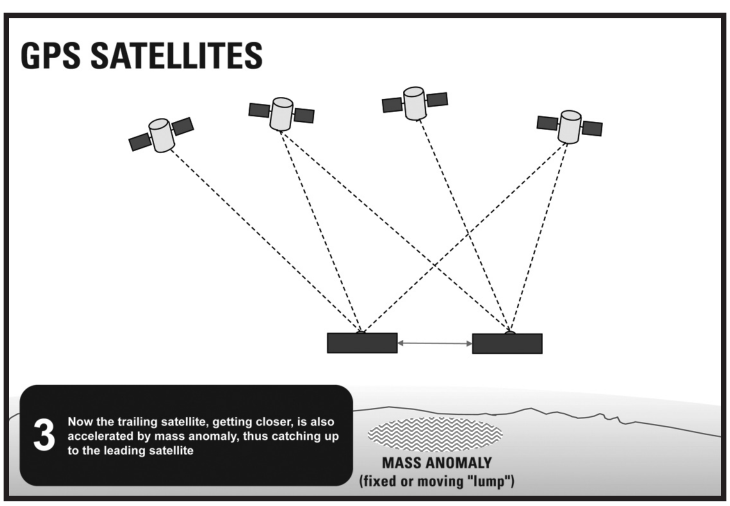
More information is available at:

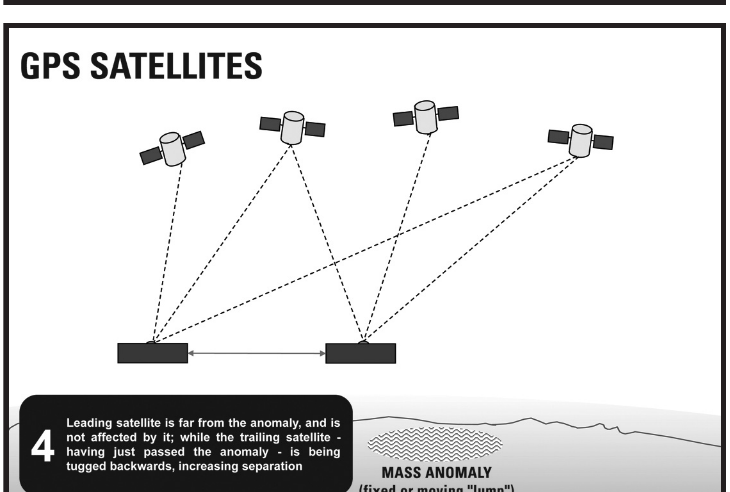
http://www.csr.utexas.edu/grace/ **http://grace.jpl.nasa.gov/**

GRACE is different ...





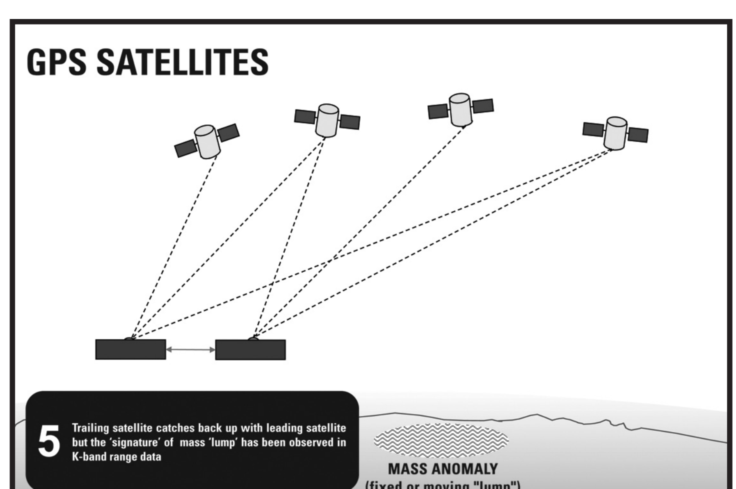




GRACE is different from most Earth Observing satellites. The experiment does not look directly at the Earth. Instead, it detects gravity changes by measuring the distance between the satellites themselves. But how does this distance measurement relate to gravity?

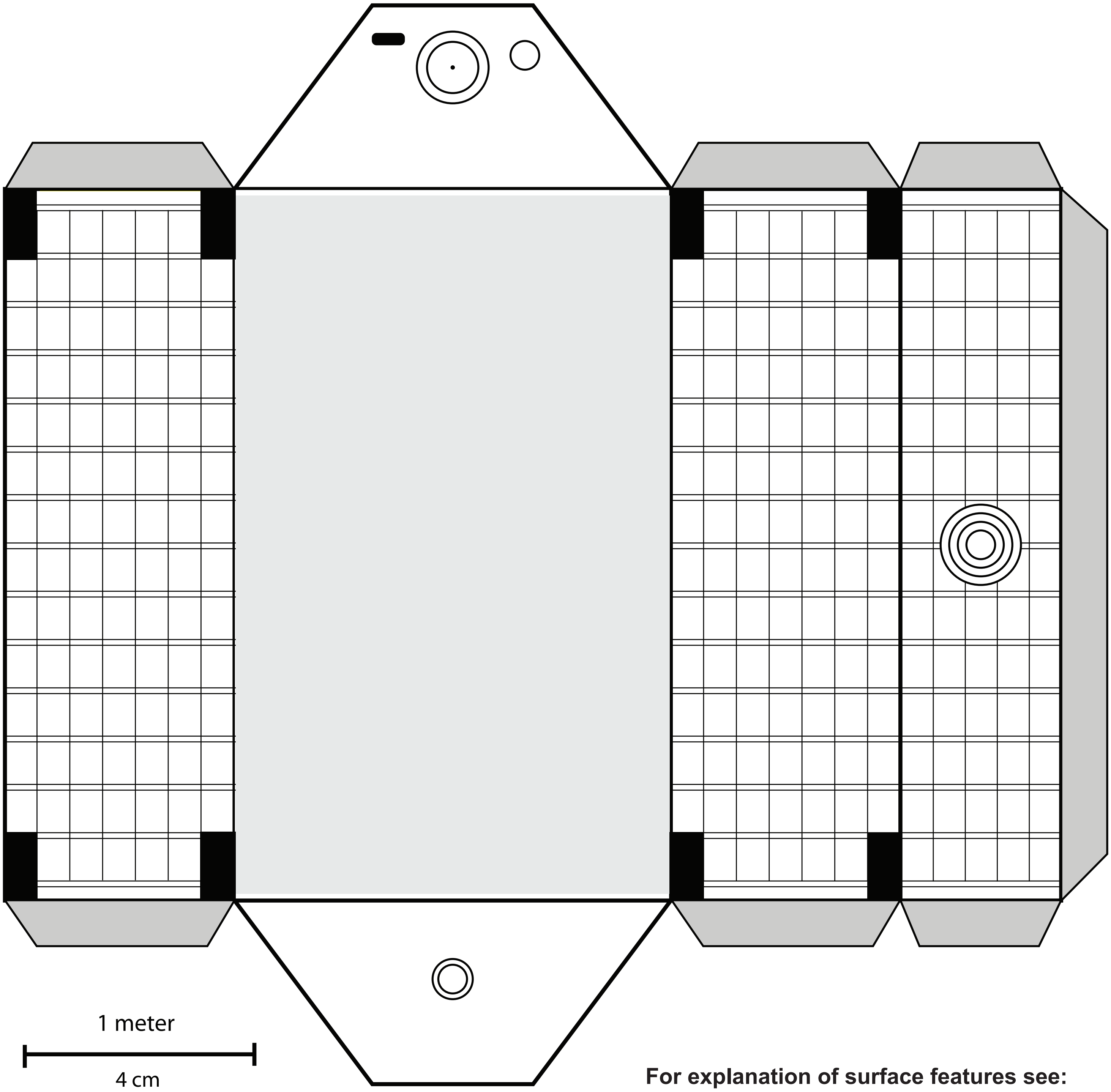
The mass within the Earth and on its surface is not evenly distributed. Molten rock flows in the Earth core, water masses move in the oceans and on the continents and atmospheric masses are also in continuous movement. The gravity force of a body depends on its mass and shape. For a perfectly spherical and homogeneous body the gravity field is simple, and symmetric in any direction. The mass distribution of our planet, however, is irregular and 'lumpy'.

As the satellites move through this uneven gravity field, the orbits of each satellite are slightly disturbed, which affects the distance between the two spacecraft. GRACE's uniquely precise microwave ranging system measures the approximately 220 km distance between the satellites with an accuracy of some microns – about one-tenth the width of a human hair! With this ultra-precise measurement, the variations in the Earth's gravity field can be mapped.



These ultra-precise measurements, combined with tracking data from the GPS satellites, allows scientists to map the Earth's gravity field with unprecedented accuracy.

GRACE MODEL



For explanation of surface features see:
http://www.csr.utexas.edu/grace/spacecraft/c1.html

Teacher: Introduce the concept of a model, discuss scales and units.

Students: Color your model using the satellite images on the front. Cut out the shape along the outlines, bend along the thick lines. Use the grey flaps to glue it together.

Extension for higher grades:
Students: The average distance between the satellites is 220 km. Using the scale given, calculate how far you have to place two satellites from each other to represent their distance.

Solution: 1 m corresponds to 4 cm on this scale, thus 1000 m corresponds to 4000 cm, that is 1km corresponds to 40 m. Thus to place the paper models at the correct scaled distance, we need to place them 220*40 m = 8800 m = 8.8 km apart.

ACTIVITY - GREENLAND

Estimating Mass of Ice Lost and Ice Loss Rate on Greenland

In this activity the student learns to interpret contour maps, estimates volume of irregular based prism, calculates mass from density and volume.

Background: While tiny changes in gravity may be negligible when solving a basic high school physics problem, they can be a critical clue to understanding the structure of the solid Earth, ocean circulation, sea ice and sea-level rise, and fluctuations in the amount of water stored above and below ground. In the Arctic, GRACE has found that the ice sheet that covers most of Greenland is shrinking. Measurements of decreasing gravity over the ice sheet indicate a decrease in the ice sheet's mass. The melting Greenland ice sheet contributes about 0.3 millimeters per year to a rising global sea level. GRACE continues its measurements to understand whether this rate of sea level rise is increasing or decreasing.

Teacher: Discuss what happens to the sea level when a floating iceberg melts, what happens when a land-based glacier melts, and which has an affect on the sea level.

Let the students examine the Greenland images on the face of the poster, and compare them to the contour maps on the back, ask them to explain in their own words what a contour map tells us. (Note, not all the changes are negative, some location gained ice mass. The students need to consider that for the total change.)

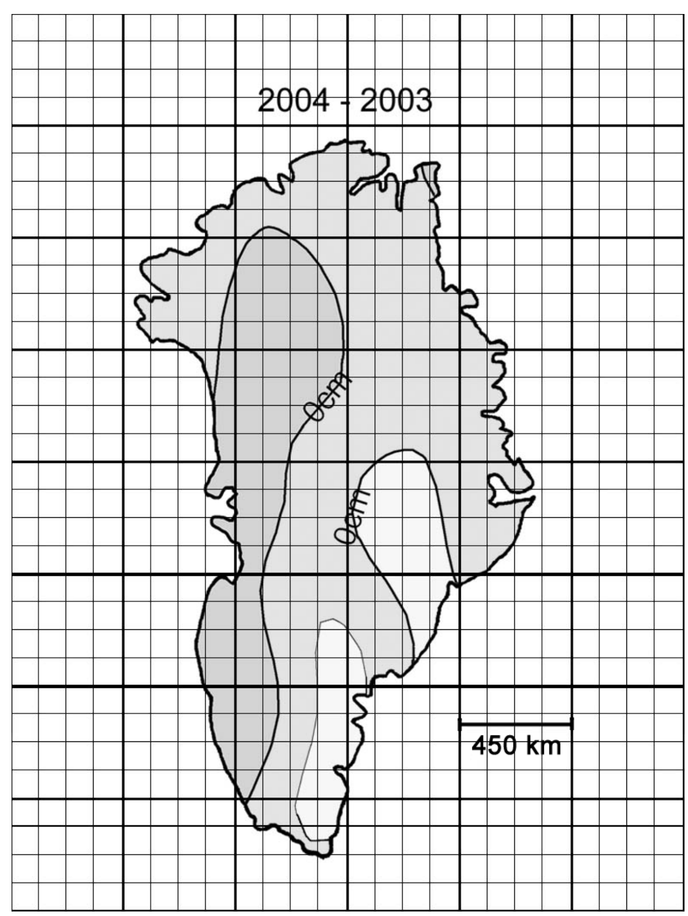
Ask students to:

- Estimate the amount of mass changed between the e.g. 2004 and 2003? - Figure out the total volume change, and use density of water to calculate mass.

- How to find out the volume of an irregular shape? - Imagine replacing the missing shape with many square based rectangular prisms line up next to each other, add up the volume of the individual prism to get the total. Between two contour lines, the heights of the prisms are the same, but which number one should use, smallest, largest or the average. How fine a grid to use, how to decide on the size of the grid?

- How many prisms are there between two contours? - Lay the grid over the maps and count the number of squares.

- How to account for squares that are not completely within the contour? - A reasonable solution: count the ones which are in halfway or more, ignore the rest. Counting will be simpler if the different intervals are colored with contrasting colors before laying the grid over.



Example of colored contour map with a 112.5 km grid overlay

ACTIVITY - GREENLAND

Estimating Mass of Ice Lost and Ice Loss Rate on Greenland

- Do it for all the different ice loss intervals.

  For a rectangular prism: **Volume = Area x Height**, the shape of the area does not matter as long as the cross section is the same all the way.

- How to calculate mass - **Mass = Volume x Density**

  Since the amount of ice lost is given as the equivalent amount of water, the student can use the density of $1 g/cm^3$ to calculate the mass. First calculate the mass of $1\ m^3$ water = 1000 kg or 1 metric ton. (Note the distance units are not consistent, the grid units are in km, the height is in cm, make sure you convert both to meters.)

- Calculate mass change for all the three years since 2003. What does a negative change mean? (Loss)

Answer: (using the average value between contours, except 120 cm for the largest change)

Mass difference (2004-2003) = $-2.25*10^{+11}$ ton = -225,000,000,000 ton

Mass difference (2006-2003) = $-4.77*10^{+11}$ ton = -477,000,000,000 ton

Mass difference (2008-2003) = $-7.13*10^{+11}$ ton = -713,000,000,000 ton

The answers between students, or students groups will differ depending on the grid placement, how did they count the partially filled squares, or due to simple arithmetic errors Ask the students to compare their results, and try deciding which is correct.

- Before calculating the mass ask students to add up the number of the different color squares. Should that number differ for the different years? (No, it always should add up to about the same, the area of Greenland. The number of squares depends on the grid size they choose.)

- If more than two answers have the same order of magnitude, they probably got it right; it is unlikely the different groups made the same mistake. If we exclude the obviously different ones, how can we improve the estimates? (The average of the results for a year is likely to be closer to the real value, than the individual numbers).

- If the results are wildly different, it is best to redo the measurements with either swapping different years between the students or groups, or repeat the exercise using larger copies with a different grid.

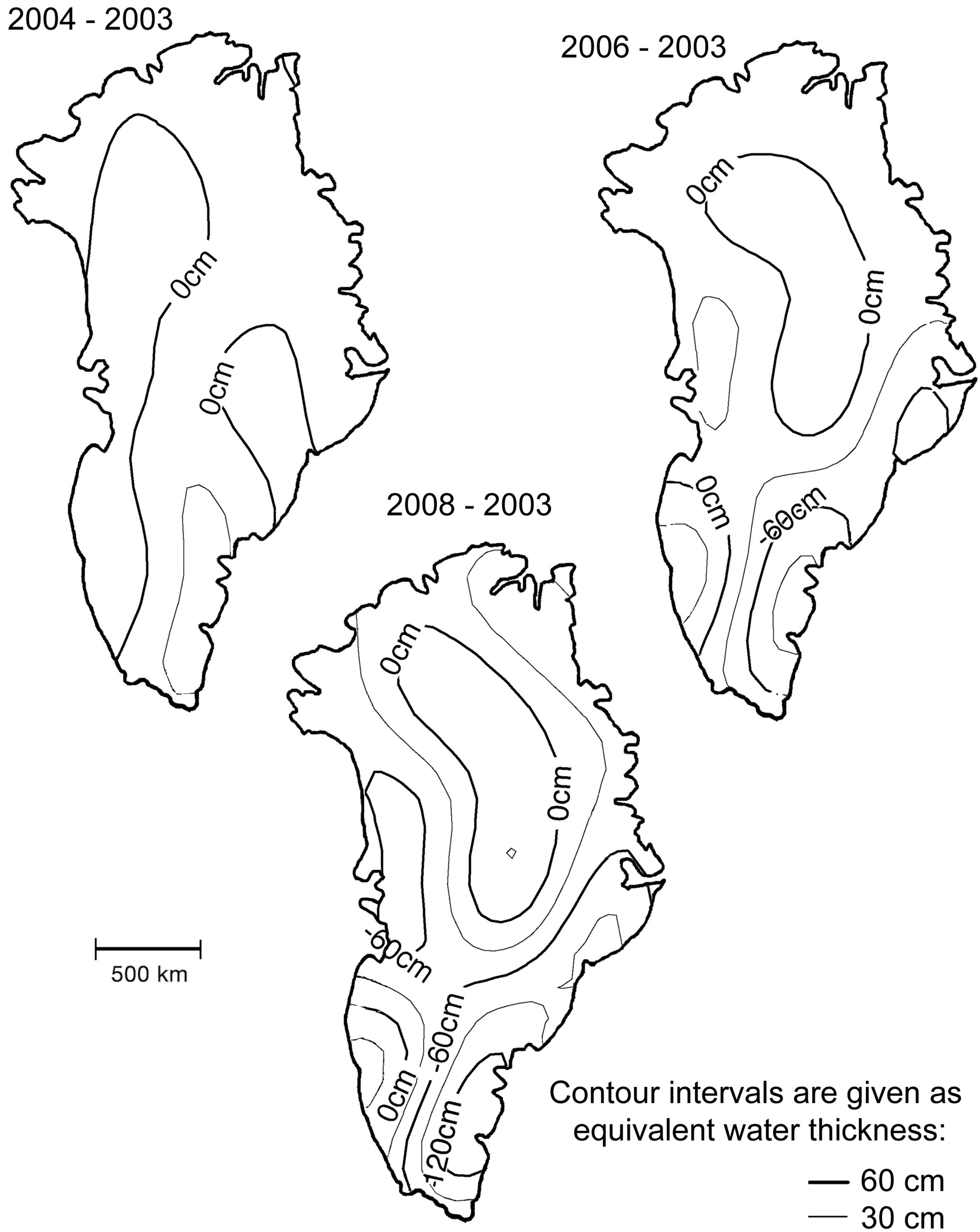
The activity can be adopted for younger students by asking them to do the coloring between the different contours.

- Ask the students to figure out what does it mean that they can see more and more contour lines? (The height of the ice, this its mass is changing compared to 2004.)

- Based on the interpretation of the contour lines/colors what direction is the change going? Toward gaining mass or losing mass? (Both 2006 and 2008 have less height/mass then 2004)

All Greenland images are courtesy of D. Chambers, Center for Space Research, The University of Texas at Austin.

Estimating mass of ice lost and ice-loss rate on Greenland



All Greenland images are courtesy of D. Chambers, Center for Space Research, The University of Texas at Austin

ACTIVITY

Designing a Colony Ship: A Thought Experiment

Congratulations! You've just been given the honor of designing the very first colony ship to go to, say Mars. Your ship needs to hold a hundred people for the eight-month journey from Earth. The doctors at NASA tell you that if you leave a hundred people in zero gravity for so long, their bones may become too weak to support them once they arrive at Mars. You have to – somehow – make artificial gravity onboard your ship. However, this isn't Star Trek and you don't have any "gravity plates". So, what can you do?

Need some hints to get you started?

- What happens when you swing a bucket of water in circles? Look at the surface of the water. Better, try this little experiment at home, but make sure you are outside. Get a small pail with a handle on it with some rope tied to the handle. Fill it less than halfway. If you just turn the pail upside-down over your head, all the water will fall out. But try this: hold the bucket out to your side and spin it quickly in a vertical circle. If you move it fast enough, the water will stay in the bucket, even when the bucket is upside-down or sideways! (It might take a little practice.)

- Now, imagine that instead of water, there are tiny people in the circling bucket. What way would the bucket-people fall if they jumped? Would they fall towards the bottom of the bucket, or out the top? Whatever way they fall is the direction of the artificial "gravity" that they feel.

How the bucket trick works: The water stays in your bucket, because whenever you spin something, you always need to pull it toward the point you're spinning it about, otherwise it would continue in the direction of its velocity. You pull the pail inwards, so the water in it gets pushed against its bottom. Gravity always pulls the water down, but your spinning keeps the water pushed away from the center. If you spin the bucket at the right speed, the water stays in place with respect to the bucket, even when it's upside down.

Do you have an idea now? Read on for one possible answer:
The simplest way we know to make artificial gravity is to spin the ship. The spinning will make everything fall toward the outer hull of the ship, thus acts like gravity, and makes the NASA doctors and the colonists happy since it keeps food from floating away when they eat!

Here are a few more things to think about when designing your colony ship:

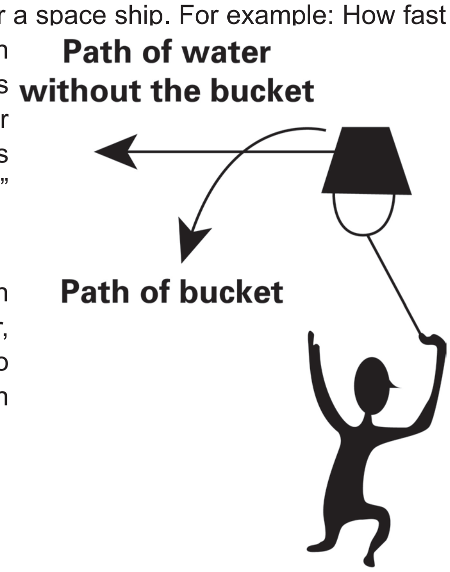
- How can you control the strength of the artificial gravity? (The faster you spin it, the stronger the gravity will be.)

- What should be the shape of your ship? Does it matter, in terms of the artificial gravity system? Hint: we want to gravity to be as uniform as possible for everyday life on the ship.

- Where will there be the most artificial gravity in your ship? Where will there be the least? Why? (Hint: If you get dizzy on a playground merry go round, where would you stand to avoid the problem?)

- Imagine if you left your ship hollow and stood on one side of the inside. You'd be held down by the artificial gravity, so everything would seem normal. Then imagine you asked a friend to go stand on the far side of the ship. He'd appear upside-down to you! Why wouldn't he fall? (Hint, think about Australians)

There are many other questions to think about when designing an artificial gravity system for a space ship. For example: How fast would you want to spin it up? The more you spin it up, the more you have to slow it down for landing. Where would you put all the things – beds, couches, desks, and refrigerators – to keep them from floating away before the ship gets spun-up? Where do you put your communications antenna, which always needs to point to the Earth, even when your ship is spinning? Will the colonists feel any sideways motion from the spinning, or will it all be "down" to the edges of the ship?



Finally, what's the difference between "real" gravity and "artificial" gravity? - If the speed at which your cabin rotates were slow enough, you would not be able to feel the difference. However, precise experiments will tell you that there is a slight deviation from "up" and "down", due to the Coriolis effect. It is the same effect, which is responsible for the formation of hurricanes on Earth.

For continuation of this exercise go on line to:
http://www.csr.utexas.edu/grace/education/activities/